3D Metrology for Process Control and Structure Integrity for Evaluating MEMS Reliability for Space Applications

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ABSTRACT

MEMS FABRICATION

MEMS fabrication processes are as diverse as their applications. Many processes borrow from conventional semiconductor fabrication but others are unique. In almost all cases, the thickness of films and film stacks are greater than in VLSI. Other examples of unique processing are anisotropic wet etching of silicon, deep RIE of silicon (up to several hundred microns deep) and high aspect ratio metal electroforming (LIGA). The often thick films (several microns) and high topography of MEMS structures place new a demanding requirements on metrology for process development, design centering and manufacturing.

BACKGROUND/MOTIVATION

MEMS Process Control

The MEMS market is a good candidate for the use of a DualBeam (FIB/SEM) system for process feedback. The device structures are complex and 3-dimensional. In some cases, critical features can not be imaged or measured with traditional top-down e-beam metrology systems.

The DualBeam metrology process for MEMS Process Control includes the automated cross-sectioning of a specified number of MEMS structures per wafer for the purpose of exposing critical buried features. The metrology information extracted from these cross sections is then used to optimize the lithography, etching, and plating processes. The technique for obtaining 3D-metrology measurements in-line consists of the following automated procedures:

- wafer alignment,
- site identification for ion beam cross-sectioning,
- ion beam milling,
- e-beam image collection,
- Width, height, and angle measurements of complex features on the captured image.

Metrology measurements collected include the deposition thickness of LPCVD polysilicon and oxide sacrificial layers, RIE etch profiles and corresponding etch rates and overetches of specific films.

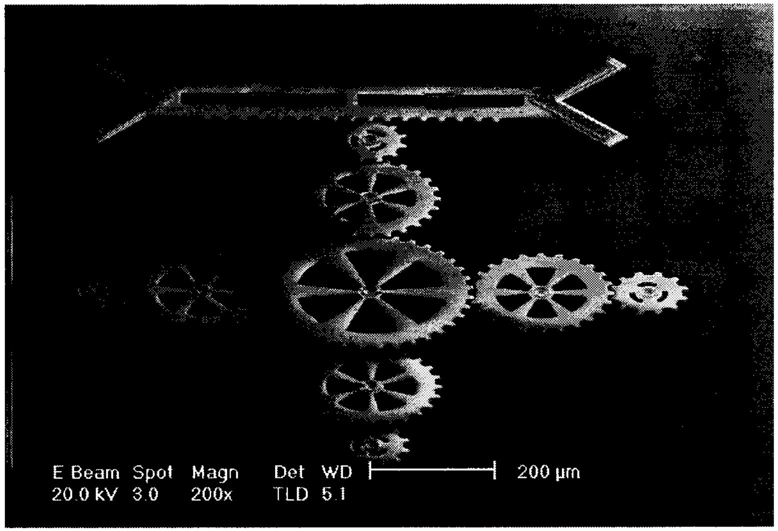
As MEMS technology matures, requirements for process control become more important. The IC industry is starting to explore 3D metrology to better understand the importance of photoresist line profiles and their effect on device yield, the MEMS community will require the same stringent control protocols to enable the commercialization of MEMS. In a DualBeam FIB system these measurements can be taken without the need for special reticles or wafer cleaving.

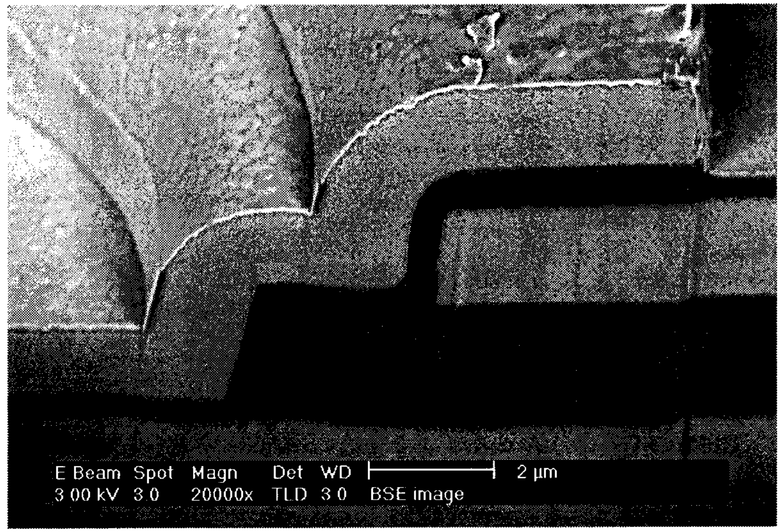
The DualBeam utilizes ion beam cross-sectioning to reveal line profiles while stepping through focus and energy settings on a Focus Exposure Matrix (FEM). A high resolution image of the lines is then collected by the electron column for metrology measurements. This process for MEMS Process control includes many of the same procedures used in the data storage market, and IC process control but with a greater demand on high magnification, depth of field and 3-D imaging performance.

Conclusion:

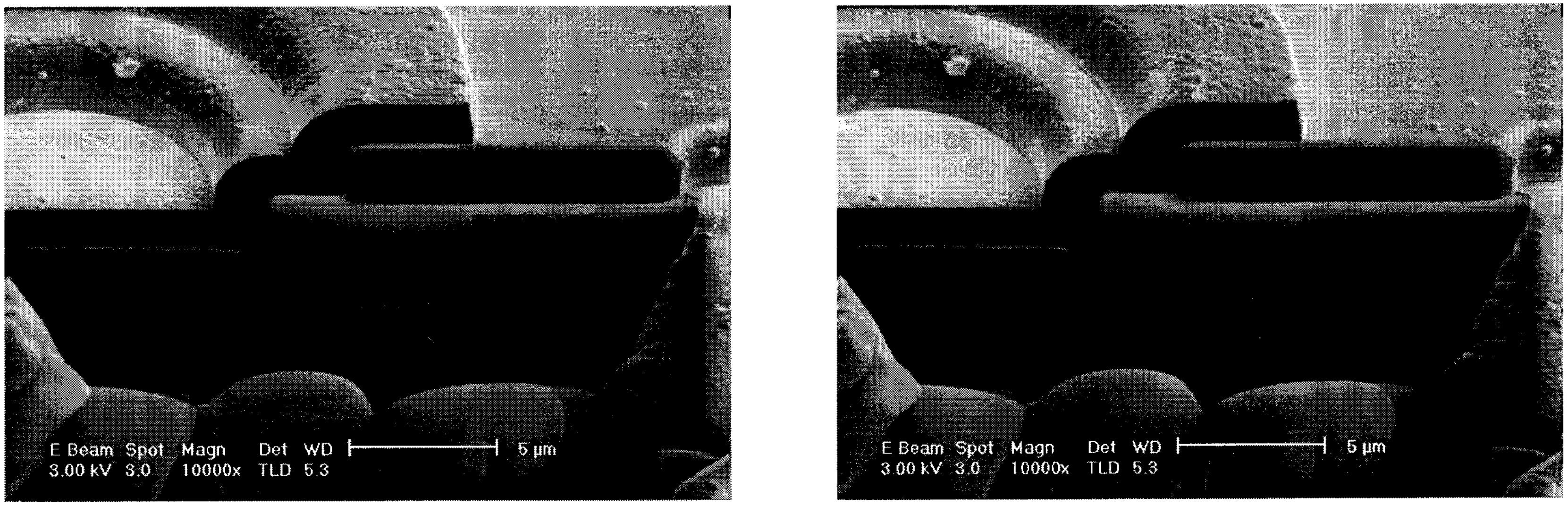
Because properties and (micro)geometries are subject o manufacturing variations there is as yet no guarantee that the "right" properties would be measured for a particular fab. Moreover, to the extent that residual stresses vary also from lot to lot, it is necessary to establish these parameters -or at least a sufficient number of indicators- for each wafer or fab.

To this end each wafer needs to incorporate one or more **test structures**, on which specialized characterization tests are performed routinely to characterize the particular fab as well defined input into the solid mechanics analysis that then produces the **reliability estimate**. It is anticipated that ultimately each foundry would have the means and capability to perform these standardized measurements to supply to the customer along with the MEMS hardware.

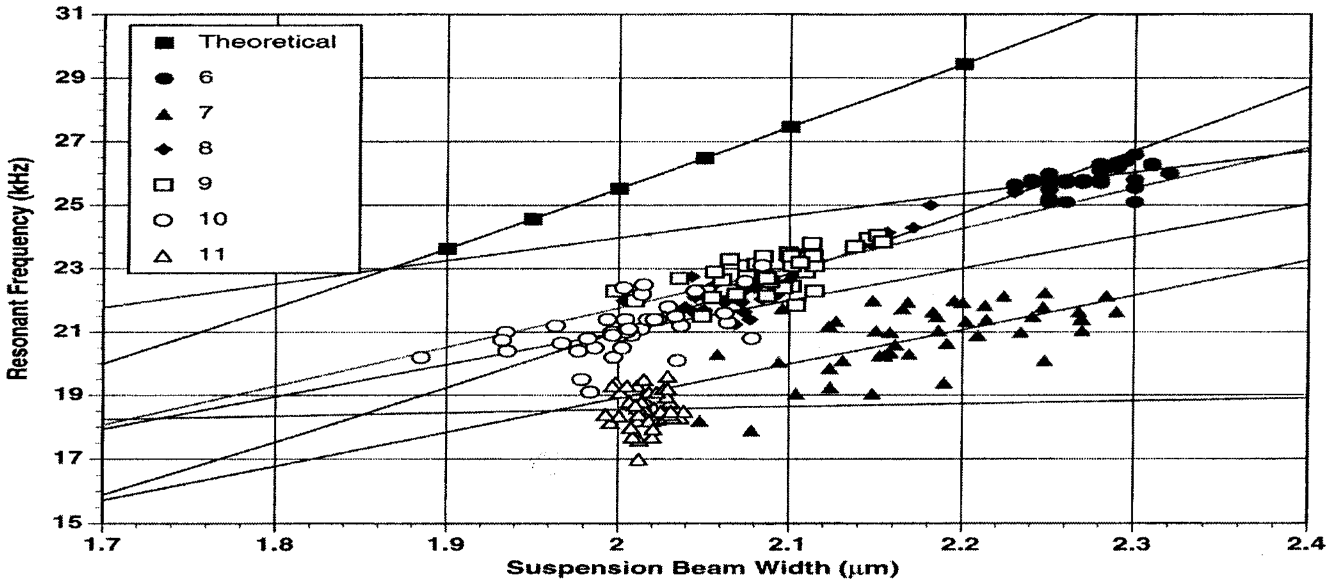




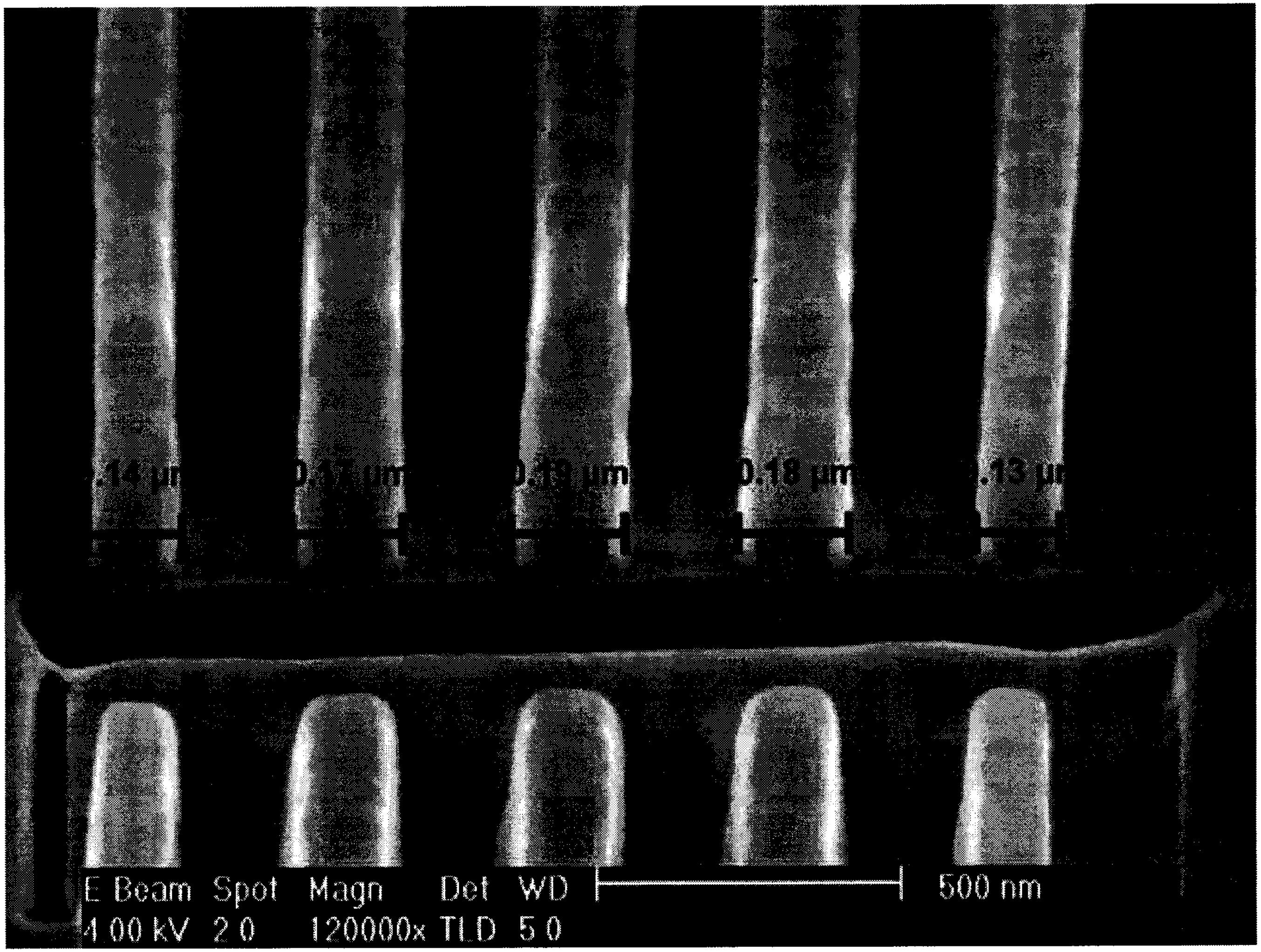
Overall of Gear as Designed and the Cross Section for Model Validation and Process Characterization



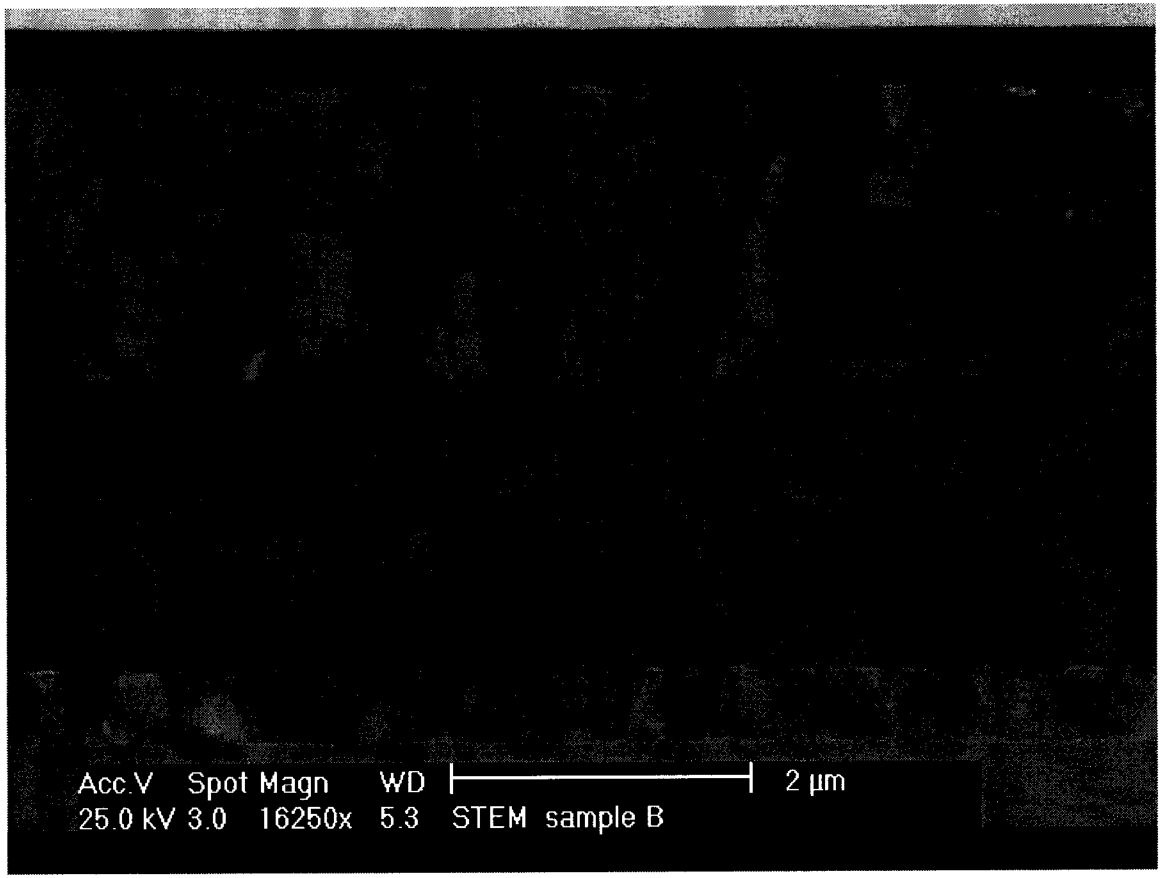
FIB Cross Section for Stereo Reconstruction for Metrology and process Characterization of a Gear



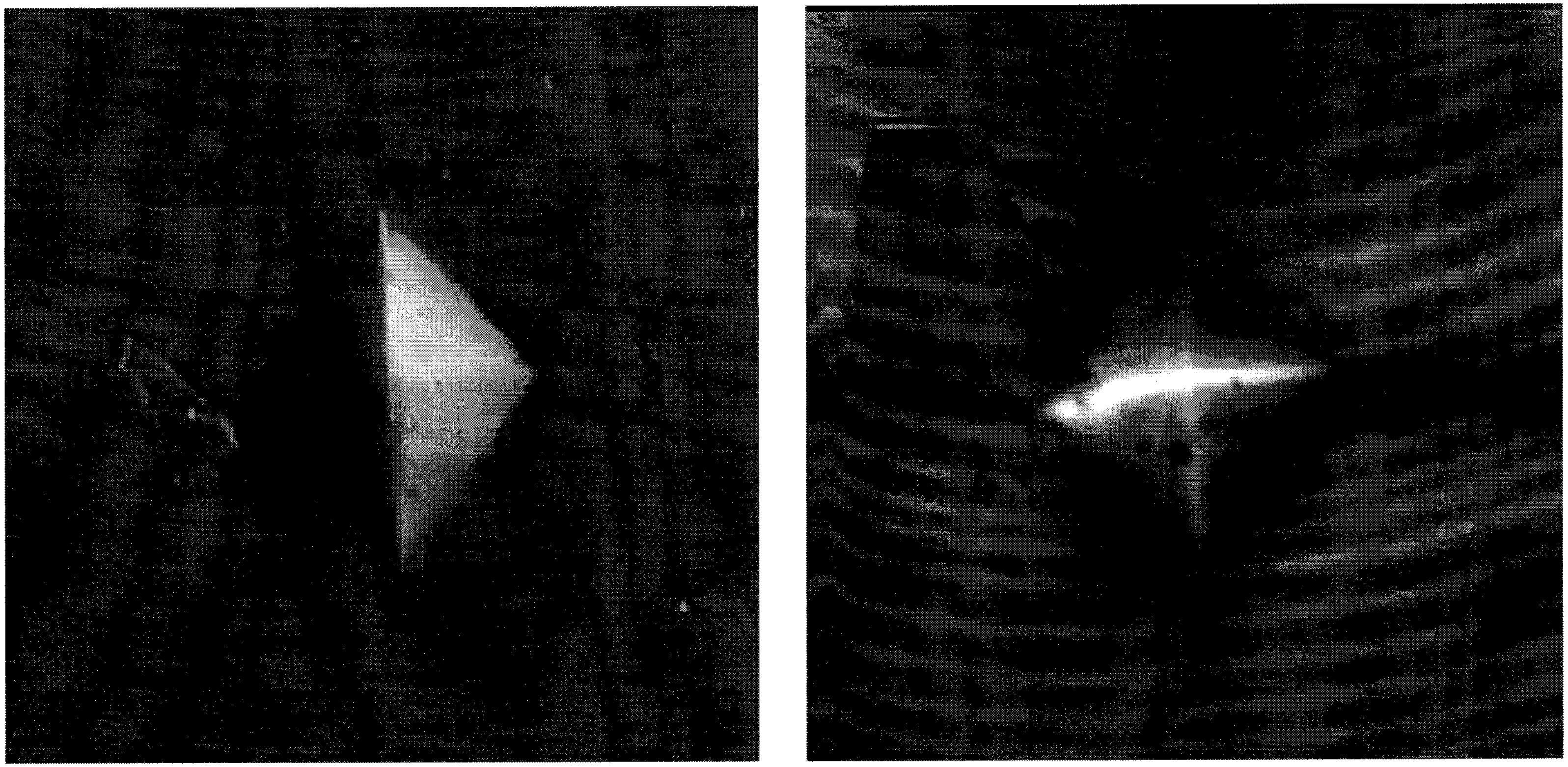
Variation in Resonant Frequency of MCNC MEMS Runs as a result of Variations in Beam Width



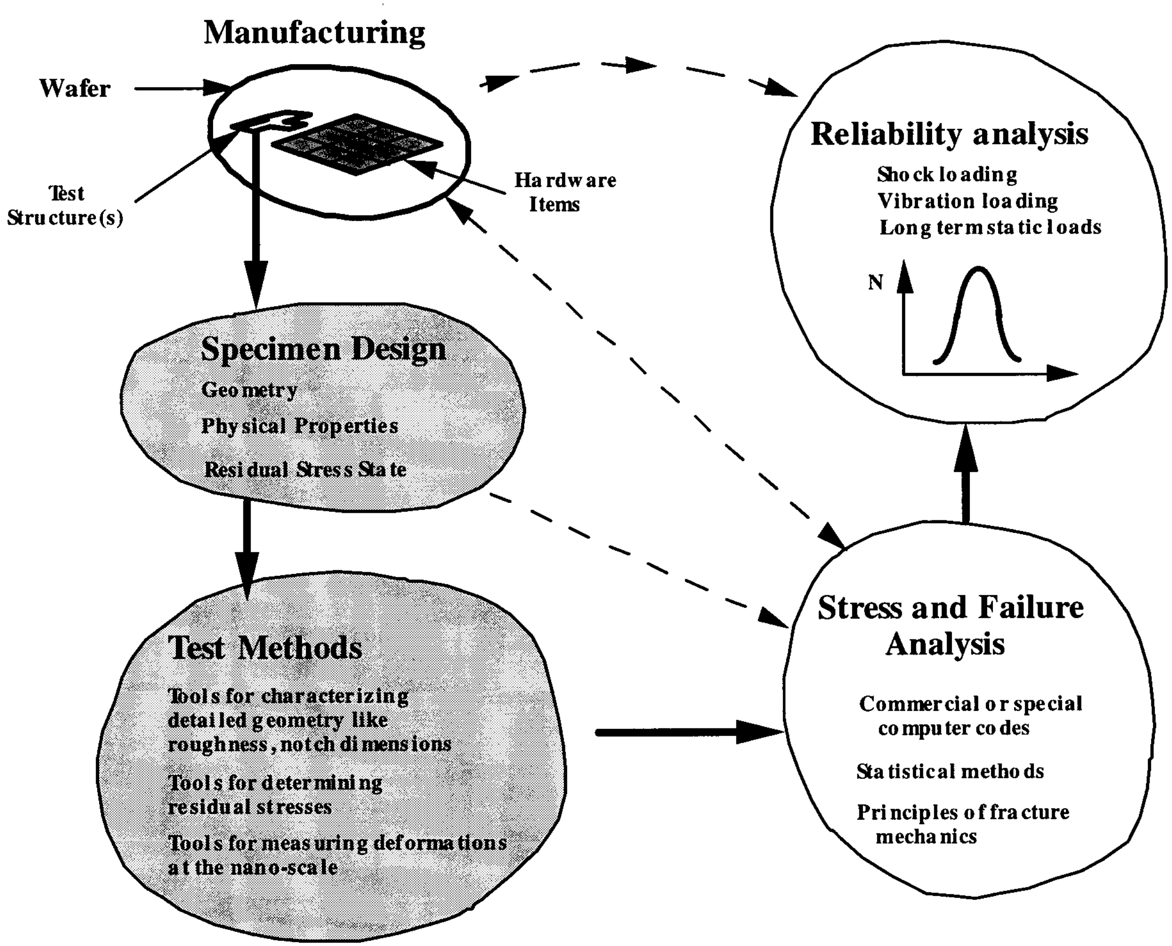
Cross Section for Dimensional analysis and Process Characterization



STEM Image of POLY 0, and POLY1 Pre Release



Secondary image of Indent on Silicon and SEAM image for Reliability Analysis



Flow diagram of interacting activities for developing an integrated reliability analysis capability.Dashed lines represent idealized operations paths